IDENTIFYING AND MANAGING PROCESS RISKS RELATED TO BIOFUEL PROJECTS AND PLANTS

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Fuels derived from biomass (stored energy in plants, wood etc.) are being developed as a renewable source of energy and the investment in biofuel production is growing. There are a number processes identified and developed for producing biofuels in the form of solids, liquids and gases. The projected market (primarily the target set by authorities for greener fuels) and the ease of production have gained attention and interest in the scientific community and in the public domain.

Unlike a typical hydrocarbon fuel production process (like crude oil refining), most of the biofuel production methods are simpler and are operable and profitable at small, medium and large scale; production capacities of operating plants ranging from a few litres per day to thousands of tonnes per year. The simplicity of the operation of some of the processes and ready availability of the raw materials has brought in many unconventional players (e.g. agricultural community and entrepreneurs) in the production of biofuels.

The dramatic rise in the number of biofuel process plants and new operators has resulted in a number of incidents resulting in loss of life and property. From reported incident statistics it could be inferred that approximately six fire and explosion incidents are reported every year from bioethanol and biodiesel industries alone in the United States [Saraf[1,2]].

The process industry is aware of the financial risks and environmental hazards associated with production and use of biofuel as an eco-friendly alternative fuel from a large number of studies, discussions, research literature and government guidelines. However, there is limited information available on the process hazards and minimal appreciation on the risk involved in the production of the biofuels.

Newer technology (especially for purification etc.), minimal operational experience with unskilled/semi-skilled operators, building and operating biofuel process plants in potentially inappropriate locations (near to vulnerable populations), all call for a detailed assessment to identify the process hazards and minimise the risks. Many operators and the public are not sufficiently aware of the risks associated with the production of biofuel.

This paper will summarise the principal hazards and significance of managing process risk in the biofuel industry. The findings are from risk assessment studies conducted for several types of biofuel projects and biofuel process plants.

INTRODUCTION

Biofuels are a wide range of fuels that are derived from biomass or bio-waste. The term biofuel covers solid biomass, liquid biofuels and various biogases. Biomass is the dry organic matter or stored energy content of living or recently living organisms like plants, wood, alcohol or bio-degradable wastes. It excludes organic materials such as fossil fuels (coal or petroleum). Some of the commonly used biofuels are bioethanol and biodiesel. These fuels (also known as agrofuel) are used for many purposes such as generating electricity and as a transportation fuel. Biofuels like biomass can be used for fuel directly by burning it or used indirectly by fermentation to an alcohol, or extraction of combustible oils.

The production and use of biofuel has increased over recent years and the trend is expected to continue. The main driving forces behind the use of biofuels are global warming, climate change, limited fossil fuel reserves, fuel prices and growing concern over energy security. Also, many of the technologies used to create biofuels are tried and trusted and the 'bio' parts of the ingredients are totally renewable.

There are a number of biofuel manufacturing plants installed in different countries. These process plants have had accidents with fatal consequences. However, unlike other manufacturing industrial sectors, the risks and dangers associated with biofuel transport, storage and processing are not well understood and dealt with appropriately. The biofuel industry incident trend (mainly fire, explosion etc.) highlights the significance of adequate hazard identification, risk analysis and management of risk management in the biofuel industry sector.

LEGISLATION

To promote the increase in biofuel production and to address the related issues (primarily the quality), a number of regulations and guidance have been put in place by legislative and administrative bodies. For example:

- A global framework for climate change was set in place on the signing of the United Nations Framework on Climate Change (UNFCC) in 1994.
- The Kyoto Protocol in 1997 has set mandatory targets for green house gas (GHG) emissions for 2012. The

aims are to reduce global emissions by at least 5% below 1990 levels in the period 2008–2012.

The European Union (EU) has introduced a number of directives that relate to renewable energy and biofuels, some of the related directives are:

- 2001/77/EC – a target of 12% of total energy use and 22% of total electricity consumption from renewable sources by 2010.
- 2003/30/EC – promotion of the use of biofuels or other renewable fuels for transport; set targets of 5.75% by energy content, of all petrol and diesel for transport purposes for member countries by 31 December 2010.

In the UK, the EU directives are implemented through a range of legislation that applies to energy and biofuels which include climate change levy, renewable obligation order, renewable transport fuel obligation and landfill tax.

LEGISLATION AND DRIVERS FOR RISK MANAGEMENT IN BIOFUELS INDUSTRY

There are a number of regulations and guidance for designing, constructing, manufacturing, storage and distribution of hazardous materials and processes involving hazardous operations. Much of the guidance is applicable or relevant for managing process risk associated to the biofuel industry and a few of them are included below:

- ATEX Directives (EU):
  - Directive 99/92/EC (also known as 'ATEX 137' or the 'ATEX Workplace Directive') on minimum requirements for improving the health and safety protection of workers potentially at risk from explosive atmospheres.
  - Directive 94/9/EC (also known as 'ATEX 95' or 'the ATEX Equipment Directive') on the approximation of the laws of Members States concerning equipment and protective systems intended for use in potentially explosive atmospheres.
- A series of guidance from UK HSE:
  - Safe use and handling of flammable liquid (HSG140).
  - Designing and operating safe chemical reaction processes (HSG143).
  - How safe is your workplace? A short guide to the dangerous substances and explosive atmospheres regulations (INDG370).
- The Health and Safety at Work etc. Act 1974, is the primary piece of legislation covering Occupational Health and Safety in the UK.

Although most of the available guidance is generic for the process industries, the guidance and principle of safety and risk management is applicable for different scales of biofuel manufacturing. However, the UK HSE advises against home production and has published health and safety warning on the domestic production of biodiesel [HSE[1]].

The principal fact exerted by all such regulations, is that the employer shall ensure that the place of work is safe to the employee and the operator of an installation is to ensure that the facility poses no additional threat to its neighbourhood or the risk from the operation is acceptable or tolerable.

BIOFUEL USE AND BENEFITS

A number of uses have been identified for biofuels ranging from biogas for home cooking to industrial scale generation of heat and electricity and from locomotive fuel additive to automobile fuel replacement. The primary use of biofuel which is developing rapidly is for use as transportation fuel. Bioethanol, an alcohol, is usually mixed with petrol; biodiesel can be used in diesel engines, either mixed with conventional diesel fuel or in pure form. It produces far less air pollution than conventional diesel fuel or petrol.

The use of biofuels over the last two decades has increased dramatically. In the Annual Energy Outlook 2008 [EIA], ethanol use grows from 21 billion litres (5.6 billion gallons) in 2006 to 90.5 billion litres (23.9 billion gallons) in 2030, which will account for about 16 percent of total petrol consumption by volume in the US. The Ministry for Energy in Thailand proposes phasing out all Octane 95 gasoline to be replaced by E10 (a fuel mixture of 10% ethanol and 90% gasoline) in the next two years. A similar trend in biofuel use is seen throughout the world.

There are many benefits that make biofuel a main alternative fuel and some of the benefits are:

- Ease of handling (less laborious): most of the biofuels are in liquid (or gaseous) form that can be pumped and transported thorough pipelines.
- Simplicity in the production process and most of the processes are economically viable for small, medium and large scales.
- Essentially free from pollutants like sulphur and aromatics (which require complicated purification process).
- Ease of availability of raw materials and can be produced on demand.
- Excellent market for the finished product, adaptable to the present technologies avoiding major modifications in engines that use fossil fuels.
- Use of biofuel generates a smaller environmental contamination and one of the best ways to reduce GHG emissions (reduced carbon emission).
- Limits the exhaustion of fossil fuels.
- Generates opportunities for agriculture.
- Promotes use of transition energies.

But the debate on such biofuels is not all one way. There are many concerns raised on the growing use of plants as a means of producing alternative fuels at the cost of producing food crops.

TYPES OF BIOFUELS

Biofuel is an abbreviation of bioorganic fuel and derived from distinct sources like household waste, wood, waste, gases from landfill/wastes (biogas) and alcohol fuel. Generally, biofuels are classified into first, second and third generation.

First generation biofuels are made from sugar, starch, vegetable oil or animal fats using conventional technology and are referred to as first generation fuels. Fuel crops can be grown specifically for energy use and include maize, corn, wheat, soyabean, sugarcane etc. The most common first generation fuels are biodiesel, bioethanol, biogas and solid biofuel as wood, charcoal or dried manure.

Second generation biofuels are made from a variety of non food crops like jatropha and miscanthus. Biodiesel produced by gasification of cellulose and conversion of the syngas into biodiesel is an example of second generation use biomass to liquid technology.

Third generation biofuels are made from algae. Algae (such as Botyococcus braunii) are low-input, high-yield feed stocks and relatively easy to grow, but algal oil is hard to extract.

For further discussion in this paper, biofuel manufacturing has been classified into small, medium and large based on the scale of production:

- Small: Biofuel production in limited capacity and mainly for domestic/personal use (not for commercial purposes). In such cases, no definite identification or plant boundary defined for the facility. For example, biogas plant based on animal wastes set in the back garden or biodiesel production in a garage with a capacity of a few hundred litres per annum.
- Large: Industrial scale production for commercial purposes where large inventories of hazardous material are stored and processed. The process could be complicated and higher product purity is attainable. Often, these kinds of manufacturing are combined plants for generation of power and utilities e.g. million litres per annum bioethanol plant with combined heat and power plant and storage tanks for raw materials, intermediates and finished products.
- Medium: Production facilities in the category between small and large where the facility is bigger than small scale. The facility will be in an identified location with a specified boundary. The facility operates with a limited inventory and often with mobile storage, e.g. biodiesel plant with raw material feed from road tanker and finished product stored in temporary storage tanks/containers.

In this context, it is worth mentioning the research in progress for mobile biomass refinery [Pool]. The idea is to set up plants in large lorries which travel around to convert any kind of biomass into liquid fuels.

BIOFUEL MANUFACTURING AND PRODUCTION PROCESSES

There are a number of mechanisms adopted to convert biomass to different forms of energy or fuels. The mechanisms can be broadly classified as thermal, chemical and biochemical.

- Thermal conversion: Heat is the dominant mechanism to convert biomass. Combustion, pyrolysis and gasification are some of the common processes and combined heat and power is an example of the application of thermal conversion.
- Biochemical conversion: The approach uses enzymes of bacteria and other micro-organisms to break down biomass. Commonly employed conversion processes using micro-organisms include anaerobic digestion, fermentation, composting and transesterification.

The processes involved (not exhaustive) in different types of biofuel manufacturing are included here to give a flavour of the chemistry and chemical engineering involved:

- *Acid hydrolysis:* A chemical process to convert cellulose or starch to sugar using acid.
- *Dehydration:* Removal of water, the methods used are physical absorption process (using a molecular sieve), azeotropic distillation (ethanol – adding the hydrocarbon benzene) and by using calcium oxide as a desiccant.
- *Distillation:* A physical separation process where components of a mixture are separated, based on differences in their volatilities in a boiling liquid mixture.
- *Fermentation:* Conversion of carbohydrates (in biomass) to alcohols and carbon dioxide or organic acids using yeasts, bacteria or a combination, under anaerobic conditions.
- *Gasification:* A process that converts carbonaceous materials, such as coal, petroleum, petroleum coke or biomass, into carbon monoxide and hydrogen.
- *Pyrolysis:* Thermal decomposition of organic material at elevated temperatures in the absence of oxygen.
- *Transesterification:* Process involves reacting vegetable oils or animal fats with alcohols.

Manufacturing methods of some of the common biofuels are briefly given below:

- *Bioethanol:* Bioethanol is mainly produced by the sugar fermentation process. Another option is by the chemical process of reacting ethylene with steam. The basic steps for large scale production of bio ethanol are fermentation of sugars, distillation, dehydration and denaturing (optional).
- *Biodiesel:* Mixing methanol with sodium hydroxide (also known as caustic soda or lye), then pouring the resulting mixture into vegetable oil.

$$\text{Vegetable oil} + \text{Catalyst} + \text{methanol} \rightarrow \text{reaction} \rightarrow \text{Biodiesel} + \text{glycerine}$$

- *Syngas:* Syngas (mainly hydrogen and carbon monoxide) is generated in both gasification and pyrolysis processes.

HAZARDS AND RISK MANAGEMENT

A number of hazards are associated with the biofuel industry in each stage of the project and plant life cycle from the concept selection through to the decommissioning. There are many other challenges like engineering unknowns, lack of reliable failure rate data, inconsistency in applicable regulations, low skills and competence and entry of new manufacturers. In addition to these, legislative requirements, corporate policy and commitments, economic benefits, reputation, public perception to the projects etc. make it obligatory to establish a system for hazard identification and risk management.

It is commonly believed amongst biofuel manufacturers (mainly small and medium scale), that process safety can be achieved by common sense; however, the fact is expertise is needed to comprehensively identify and manage biofuel manufacturing risks. Unlike other similar manufacturing industries, often no systematic approach is followed to identify and address all process hazards at each stage of the plant life cycle, especially in domestic or small scale production.

A good guidance for managing risk is given in the HSE publication 'Five steps to risk assessment' [HSE[2]]. The steps are:

(1) Identify the hazards.
(2) Determine who might be harmed and how.
(3) Evaluate the risks and decide on necessary measures.
(4) Record the findings and implement them.
(5) Review the assessment and update as necessary.

HAZARD IDENTIFICATION

In process safety and loss prevention, it is said, 'once the hazards have been identified, half the battle is won' [Mannan]. A number of hazard identification methods and techniques are available and practiced. Different methods are required at different stages of a project and also the depth of the study depends on the complications and extent of risk from the facility/operation.

It is noticed that for large biofuel manufacturing, some kind of formal hazard identification has been performed, whereas for medium and small scale production, hazard identification is often limited to the knowledge of the owner or operator. In this paper, a list of typical process hazards (not exhaustive) associated with the biofuel industry that need to be considered in the risk management process is included. The information is based on a number of hazard identification studies carried out for industrial scale production of bioethanol, biodiesel, syngas plants and from incident investigation reports involving accidents in biofuel facilities.

For the purpose of discussion, the hazards associated with the biofuel industry are categorised as follows:

- Materials and properties.
- Operations and handling.
- Projects, installation and commissioning.

HAZARDS FROM MATERIALS

The principal hazards from materials in the form of raw materials, catalysts, intermediates and finished products include:

- Fire hazards.
- Explosion hazards and overpressure releases.
- Runaway/uncontrolled reaction.
- Toxic hazards.
- Steam flashes.

Chemical and physical hazards associated with some of the common materials used/handled in the biofuel manufacturing are given below:

Methanol, ethanol, isopropanol are classified as Class IB flammable liquids (flash points below 22.8°C and boiling point higher than 37.8°C) and can readily catch fire at room temperature.

Ethanol and mixtures with water greater than about 50% ethanol are flammable and easily ignited. Ethanol has been shown to increase the risk of contracting cirrhosis of the liver, multiple forms of cancer, and alcoholism. Ethanol is highly hydrophilic and potentially corrosive.

Methanol (used in biodiesel manufacturing) is both a toxic chemical and highly flammable. Methanol exposure on a small daily dose causes cumulative damage to the body, possibly leading to blindness and death. It is also explosive and similar to petrol when mixed with caustic soda. There is a serious risk of fire and explosion as methanol is highly flammable.

Sodium hydroxide (used in biodiesel manufacturing) is extremely corrosive. It can cause burning to unprotected skin and is particularly damaging to the eyes. Stirring the liquid can often produce a fine mist of liquid droplets. If this mist is inhaled, severe irritation of the respiratory tract and breathlessness can occur. Accidental swallowing can cause major damage to the throat lining and digestive system.

Sulphuric acid is a corrosive hazard. The main occupational risks are skin contact leading to burns and the inhalation of aerosols (severe irritation of eyes and mucous membranes). Although sulphuric acid is non-flammable, contact with metals in the event of a spillage can lead to the liberation of hydrogen gas. The dispersal of acid aerosols and gaseous sulphur dioxide is an additional hazard of fires involving sulphuric acid.

Syngas is both toxic and flammable due to its composition. Both carbon monoxide and hydrogen are toxic and flammable and are the main components of syngas.

Wood chips and saw dust are the main biomass raw material for biofuel production; though the raw material is not considered to be hazardous, in some forms or under certain storage conditions, the raw materials such as sawdust and woodchip pile become a fire hazard (especially when moist). Woodchip piles have the potential to heat internally and spontaneously combust if not managed appropriately. Spontaneous heating is caused when heat produced by the microbial decay of wood is not readily dissipated [OFM]. Fires occur while heated chips are tried to be separated when they are exposed to sufficient air resulting in combustion.

HAZARDS FROM OPERATIONS AND HANDLING

Operational accidents in the biofuel industry range from slips, trips and falls to major incidents like fire and explosion. Hazards, causes, hazardous events and related consequences during operation and handling (storage, processing, handling etc.) are given below:

Storage of Flammable and Toxic Materials
This includes raw materials, additives, intermediates, finished products and by-products in different forms/phases, sizes and shapes, temperature and pressure as required by the process.

- Hazardous material inventory – hazard from bulk storage of flammables and toxics. It is sometimes noted that the inventory of hazardous materials is not proportional to the production requirements (more than design intent) which increase the hazard potential.
- Layout of storage – inadequate spacing/separation (leaks and spills affecting nearby storage or facility). Flammable area not determined and maintained, potential source of ignition (flames, hot surfaces etc.) in the proximity of potentially explosive atmosphere.
- Inadequate labeling – this could lead to selection of wrong chemical or wrong batch of material.
- Lack of earthing, grounding, bonding to avoid electrostatic hazards and protecting from lightening. Damage of materials due to inadequate protection from adverse weather condition (e.g. feedstock storage in open yards).
- Deviation from design intent – mobile storage becomes temporary process vessel e.g. raw materials pumped from tank trucks directly to process plant. Related treats are source of ignition (trucks) near to process area, tanker/truck drives away whilst unloading etc.
- Hazards from long term storage of unsaturated compounds (lower melting points resulting in release of flammable vapours).
- Pressure or vacuum applied over the designed limits.
- Inadequate supply of appropriate raw materials and or raw materials with properties outside the process design intent/limits (e.g. municipal waste).

Processing of Hazardous Materials
One of the major hazards is the accidents that could result from biofuel manufacture is release of flammables, toxics and corrosives. This could be as a result of a number of reasons related to process equipment, machinery, operating parameters, control and instrumentation etc. No or inadequate control system to measure and manage level, pressure, temperature, quality resulting in deviation from design intent by going out of the operational limits. Some examples of the hazards related to processing is given below:

- High operating or storage temperature/pressure (e.g. leading to process runaway).
- Overflow of tank, vessel, reactor or tanker.
- Lower temperature (solidification of biodiesel often resulting in plugging).
- Improper selection of appropriate equipment/machinery/rated vessels/pipe work suitable for the process.
- Inadequate installation, inspection and maintenance.
- Use of unclassified equipment and machinery in explosive atmosphere.

Hazards from Batch Processing
Most the biofuel manufacturing adopts batch processes and there are specific hazards associated with batch processing. Often violent chemical reactions result due to poor mixing, making too much at once or making a mistake with the recipe like getting the quantities wrong or adding the chemicals in the wrong order e.g. adding methanol to hot oil in biodiesel production.

Material Handling
A range of materials in solid form, liquid form and gaseous form are transferred between equipment, process vessels, storage etc. This involves a number of tools and transfer system from shovel to conveyor system to pipelines and pumps. In smaller plants, often manual handling will be the main means of material handling. Manual handling of hazardous materials results in occupational injuries and sometimes fatalities. Some of the related hazards are given below:

- Material loss, damage due to inadequate or improper conveyor system.
- Poor housekeeping leading to dust hazards and dust explosion hazards.
- Release from pipelines, vessels, valves etc.

Other Related Hazards
A number of other hazards associated indirectly to the main biofuel manufacturing such as hazards from plant modifications, hazards to environment and neighbourhood from process upsets/deviation etc. A list of such activities and hazards are given below:

- Hazards from allied works
  - Physical activity (maintenance, repair etc.) on live equipment, vessel or reactor.
  - Hot works on flammable storage.
  - Confined space entry (asphyxiation).
- Waste stream disposal that creates additional health and safety risks to individuals and the environment. Glycerol and wastewater are two of the most prevalent waste streams derived from the biodiesel process.
- Utility supplies such as super heated steam, nitrogen under stored pressure, high voltage electricity etc. are potential sources of hazards. Some of the hazards are:
  - Burns from steam.
  - Nitrogen system over-pressurisation.
  - Electric shock.
- Improper lighting and inadequate ventilation are two other significant hazards especially in confined areas and buildings.

HAZARDS FROM DESIGN, CONSTRUCTION AND COMMISSIONING

Typically, biofuel plants mainly small/medium scale and occasionally large scale plants are built in an existing facility/building or near to an existing facility/building/plant. Some of the hazards are very significant when the existing facility (old barn, garage or storage deport) is modified and converted to a biofuel processing facility. One of the common failures is failing to recognise the additional requirements to adhere to, e.g. building regulation codes, electrical installation requirements etc. If the associated hazards in conversion are not identified and addressed, the facility as such could pose high risk due to operation.

The following are some of the causes associated to biofuel plant projects that may result hazards and hazardous events:

- Improper selection of:
  - The technology or methodology for the manufacture.
  - The chemical and raw materials used for the production.
  - The location of the facility.
- Inadequate facility for the selected process:
  - Land area.
  - Nearby facility and effects from and on them.
  - Proximity to utilities like water, steam, power etc.
- Unsafe design and layout:
  - Inadequate separation distances (to restrict the spread of fire etc.).
  - Inadequate design specification (not for maximum design pressure etc.).
  - No access for inspection, maintenance etc.
  - No provision of emergency escape.
  - Thermal radiation from open flames/flares or equipment/vessel operating at high temperature (no or improper insulation etc.).
- Faulty construction and commissioning:
  - Use of inappropriate material of construction of the facility (incompatible for the material handled/ processed).
  - No/improper foundation.
  - Inadequate strength of load bearing members.
- No/inadequate provision for:
  - Ventilation.
  - Lighting.
  - Rest and cleaning.
  - Weather protection.
  - Protection from external factors like vehicle collision, attacks from animals/pests etc.
- Inadequate provision for pressure relief, safe discharge of dangerous release and overpressure protection.
- No provision for remote monitoring and control of the process.
- Provision for production using temporary/make shift arrangements.
- Inadequate assessment of hazards in establishing connection to existing facility for sharing power, utilities, structure etc.

INCIDENTS – DISCUSSION

A number of incidents have been reported involving biofuel processing, storage and handling. The accidents reported are from all kinds of biofuel production irrespective of scale or of the type of production. A detailed analysis of the investigation reports and accident data is not carried out for this paper; however, some of the incident causes reported is given below:

- Methanol spillage igniting and fire spreading to storage tanks.
- People being burnt by sulphuric acid due to poor training/supervision/suitability.
- Small processors (biodiesel) exploding due to accidentally switching on electric immersion heaters.
- Pipe work bursting due to use of incompatible materials.
- Small fires escalating to large fires due to:
  - Using plastic reactor vessels.
  - Facility not adhering to building codes, old and inappropriate wiring and separation from adjacent building e.g. barn separated by only wooden panelling (not fire-resistant).
  - Absence of fire extinguishers or fire extinguishers not operational or not operated properly.
- In process control, resulting in mixture splashing or boiling over, causing serious burns.
- Tank overflow due to inadequate level control (the level gauge not suitable for the range of materials with different densities).

It should also be noted that there will be a number of incidents and accidents (mainly from small scale production) which are not reported, investigated and analysed. In addition, lack of records on operational parameters, trends, near misses etc. from the biofuel industry does not help to analyse the deviation and reduce risk.

Crisis Management

Lack of emergency planning and preparedness is one another factor that may result in inadequate mitigation and often escalation of minor incidents to major. This includes:

- Inadequate means for detection and isolation of hazardous releases.
- Inadequate means for active and passive fire and explosion protection.
- Inadequate personnel and inadequate training for emergency response personnel.

Human Factors

Biofuel facilities are often designed and operated by not so suitably qualified and experienced persons. Lack of training, awareness and supervision often leads to poor judgement, inadequate decision making ultimately which may result in major process upset or incident. Some of the issues related to human factor are:

- Lack of training and understanding could miss/oversee major process deviation that could result in fatal accidents.
- Lack of awareness of health hazards and performing activities without personal protective gear that could result in injuries and illness.

- Production without standard operating procedure or instruction, especially in small and medium scale production facilities.

RISK MANAGEMENT

Risk management is the term used to cover the whole process of identifying and assessing risk, setting goals and creating and operating systems for their control. Though the biofuel manufacturing facility often does not come under major accident hazard regulations, it is prudent that the risk from the biofuel industry is assessed and managed considering the nature of hazards and the stakeholders involved. The depth of risk assessment should be proportional to the extent of risk involved in the process and facility.

Effective risk management can assist the biofuel industry in the prevention of catastrophic events; it can also enhance operator/employee knowledge of operations, improve technical procedures, maintain accurate process safety information and increase overall facility productivity. Since many of the current biofuel manufacturers are small operations, a set of guidelines encompassing process safety management, but less rigorous, shall be developed for such facilities.

A detailed risk management process is not covered as part of this paper. The generic approach for process risk management shall be adopted for the biofuel industry where hazards are identified, assessed and analysed systematically using appropriate tools and methods by suitably trained and competent persons. Any gaps or shortfalls identified to control risk should be addressed appropriately. In general, the preference for necessary control measures should be:

- Preventive over mitigative.
- Passive over active.
- Engineered over administrative.
- Controls with the highest reliability.
- Controls closest to the hazard.

Projects involving biofuel manufacturing, storage and/or transport should be treated as a process involving hazardous materials and hazardous operations. All necessary steps for risk management should be carried out at each stage of the project, to establish a risk management system and ensure the effectiveness of the system by inspection, maintenance and auditing. Some of the considerations and control measures suggested for the risk management of the biofuel industry are given below:

- Use suitable materials (inherently safe) for the construction of vessels, reactors and pipe work.
  - Choose steel over plastic for biodiesel reactors. Avoids leaks from fittings due to operational cycles (temperature changes) and also provide some protection against fires (e.g. from methanol release) nearby.
  - Avoid use of plastic piping for the transport of any fluid containing methanol, especially downstream of any pump.
- Use electrical and mechanical equipment that conforms to required regulations for explosive areas that may contain methanol vapour (methanol vapour is explosive at just 5% concentration with air).
- Use a separate vessel for heating vegetable oil and do not to install electrical heating elements in biodiesel reactors.
- Well written instructions and standard operating procedures to avoid accidents from wrong mixture or wrong recipe. Establish general operational guidelines:
  - Advise not to add methanol to hot oil.
  - Never add water to acid or methanol to caustic soda.
- Always have very good ventilation and lighting in the workspace.
- Never make biofuel in the house or in a garage adjoining, or part of, a home.
- Facility to be operated by suitably trained and qualified responsible person only.
- Ensure good housekeeping and establish an emergency plan.

CASE STUDY – RISK ASSESSMENT OF A BIODIESEL PRODUCTION EXPANSION PROJECT

The task involved identifying the process hazards, performing consequence, severity and failure frequency estimation and analysing the risk to the installation, its neighbourhood and the workforce. The scope of the project was to up-rate the production from pilot scale to industrial scale (ten thousand tonnes per annum) without major changes to the infrastructure and facilities.

A desktop hazard identification exercise was carried out using a HAZID prompt list and spreadsheet tool involving project team and design engineers. Site visits and interviews with field operators and project personnel were carried out. DNV's Phast was used to estimate the consequence extents and the estimates were assessed against the UK HSE's impact and risk acceptance criteria [HSE[3]].

The assessment found that the risk to personnel near to the process area was not acceptable and required immediate attention. The storage and handling facilities were temporary in nature and hence many hazards were identified in the handling of the hazardous materials that required to be addressed with urgency. Some of the main findings and the recommended measures to reduce risk are given below:

Risk to Operating Personnel

The control rooms (make-shift portacabin type) were placed just next to the process plant (within 5 m) and there was no passive/active fire and explosion protection to the control rooms. It was recommended to relocate the control room (increase the separation distance) to reduce potential impact. Additional provisions were suggested to improve remote monitoring of process control in order to minimise the frequency of operator visits to the process area.

Hazardous area classification was carried out and use of appropriate equipment and machinery meeting DSEAR requirements was recommended. Further, the project engineering team was asked to design appropriate flammable storage (which was in temporary containers) with suitable fire protection systems. Permanent storage (fixed tanks) for raw materials, intermediates and finished products complying with industry standard and regulatory requirements was also suggested. Product movement (trucks) were stream-lined and a separate entrance and dedicated route was implemented.

Risk to Maintenance and Project Personnel

For the capacity expansion, a number of contractors were at site and a lot of construction activities (involving hot works) were in progress near to hazardous areas (potential explosive zones). The risk reduction measures suggested were to establish and implement a permit-to-work system, relocate rest rooms (portacabins) and workshops (involving welding and cutting etc.) to the farthest point away from the process unit and storage area. Also, improving the awareness of the process hazards and emergency procedures was suggested.

Risk to Office Personnel

The office and engineering team was set in a nearby existing building and was not fit for the purpose. The existing means of communication were not sufficient to alert the office personnel in case of an emergency. An occupied building risk assessment was carried out and suitable measures to improve passive protection (including blast overpressure rating), ventilation, lighting, means of fire and gas detection and alarm (including radio communication and public addressing system) were recommended.

Offsite Risk

The installation was in a non-residential area and the consequence assessment predicted no significant process impacts offsite. However, part of the production facility (storage and preparation) was carried out in a warehouse building and the building was shared with another possessor (as storage depot). The recommendations were to relocate the storage of flammable materials from the building, to establish suitable emergency escape routes (involving all stakeholders), and improve fire protection rating of the building (especially the boundary/separation wall). An awareness session for the parties involved on the hazards and nature of operation of different parts of the site and a periodic review were suggested.

The findings were addressed and the recommendations were implemented by the facility owners. A policy for health, safety and environment was put in place by the management. A standard operating procedure was established identifying key tasks and how to perform them. Skills and experience levels for employees were defined and a suitable training and awareness system was also implemented.

CONCLUSION

The use of biofuels as an alternate to conventional energy sources is a growing trend across the globe. By increasing the production and use of biofuels, the risk associated has also increased and many incidents involving biofuels have been reported. Biofuels themselves pose minimum hazard, but the materials involved in the manufacturing and the production processes pose significant health and safety risks for individuals and the environment. The industry has acknowledged the significance of addressing financial risk and environmental risk, but in many cases safety is omitted due to the simplicity of the process and lack of awareness of the potential hazards.

From experience, it is noted that a primary cause of the accidents is due to the belief that in such a simple process it is impossible for things to go wrong. This belief is a factor in all kinds of industries, but even more so in biofuel plants where lack of experience and a simple process are combined to produce an environment in which errors occur.

This paper listed a range of biofuels and the processes involved in the production of different biofuels. Hazards associated with the design, manufacturing and handling are summarised based on design reviews and risk assessments, together with an overview of the common accidents reported in the industry. A brief description on the requirement for risk management and the steps involved is also included. The discussion about the process risks associated with biofuels highlights the necessity to select appropriate manufacturing technology, use expert knowledge, identify hazards and ensure effective risk management systems are in place during the entire plant life cycle.

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